

WEPP MODEL EROSION EVALUATION UNDER FURROW IRRIGATION

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Summary: The WEPP model was primarily designed for predicting erosion under rainfall conditions, but procedures have been added to predict soil erosion from furrow irrigation. Predicted runoff and infiltration using WEPP compared reasonably well with measurements from an 85-m long field segment, but predicted values were poorer from two fields that were longer than 200 m. Soil erosion was not adequately predicted using WEPP-defined soil parameters. Predicted soil erosion was still unacceptable after attempting to adjust soil parameters to fit furrow irrigated conditions. Some relationships in the WEPP model need to be changed before accurate soil erosion predictions can be achieved for furrow irrigated fields.

Keywords:

Furrow irrigation, Erosion prediction, WEPP.

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WEPP Model Erosion Evaluation Under Furrow Irrigation

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Abstract

The Water Erosion Prediction Project (WEPP) model simulates furrow irrigation hydrology, equates furrow erosion with rill erosion processes, and uses soil parameters derived from rainfall simulation and averaged climate data. Our objective was to evaluate the WEPP model for furrow irrigation by comparing predicted infiltration, runoff and soil erosion with field measurements from two separate studies. One study tested tillage treatment effects on an 85-m long field segment, which was approximately the upper third of the field. The other study tested inflow rate effects on 204- and 256-m long fields.

Predicted annual runoff was within 5% and infiltration was within 25% of measured values for the 85-m long field segment. On the two longer fields with four overland flow elements, predicted annual infiltration was 50 - 80% greater than measured for one field and 15% less than measured for the other field. Consequently, predicted annual runoff was 1/3 to 2 times the measured values. No soil loss was predicted when using WEPP defined critical shear (3.5 Pa) and rill erodibility (0.0215 s m^{-1}) parameters for Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic calciorthid). WEPP over-predicted annual soil loss by 2 - 15 times when critical shear and rill erodibility were adjusted to 0.72 Pa and 0.0021 s m^{-1} respectively. The model also failed to predict any erosion during irrigations with as high as 70 kg m^{-1} soil loss. Some of the erosion prediction error may result from WEPP using a linear relationship between detachment capacity and hydraulic shear. Power functions had 0.03 - 0.22 higher coefficients of determination than linear functions for 26 of the 33 WEPP soils.

Introduction

The goal of the Water Erosion Prediction Project (WEPP) was to develop new water erosion prediction technology for soil and water conservation planning and assessment. The WEPP model includes an irrigation component for estimating soil loss from sprinkler and furrow irrigated fields. Similar erosion processes (i.e. soil detachment and transport) occur during irrigation and rainfall. However, the systematics of furrow irrigation erosion differ from the simulated rainfall conditions that were used to define soil parameters for WEPP. Water initially flows on to dry soil during furrow irrigation, but rainfall moistens soil before runoff begins to flow in rills. Furthermore, flow rate decreases with distance in a furrow but usually increases with distance in rills under rainfall conditions.

The hydrology component of WEPP is critical to erosion prediction because rill erosion is estimated as a function of hydraulic shear (Lafren et al., 1991). Furrow irrigation hydrology in WEPP is based on furrow irrigation processes. Infiltration is calculated with two-dimensional infiltration equations presented by Fok and Chiang (1984), which are described in the WEPP technical documentation (Flanagan and Nearing, 1995).

The WEPP model categorizes soil erosion into rill and interrill processes. Interrill erosion involves soil detachment and transport by raindrops and sheet flow. Rill erosion processes describe soil detachment, transport and deposition in rill channels (Flanagan and Nearing, 1995). Detachment in rills occurs only when hydraulic shear exceeds the critical shear of the soil and if

the sediment load is less than the rill transport capacity. If the sediment load exceeds the transport capacity, sediment deposition occurs. Furrow erosion in the WEPP model is assumed to be the same as rill erosion under rainfall conditions.

Rill detachment by flowing water is calculated by

$$D_c = K_r(\tau - \tau_c)^a \quad (1)$$

where D_c is detachment rate of clear water ($\text{kg s}^{-1}\text{m}^{-2}$), K_r is rill erodibility (s m^{-1}), τ is hydraulic shear of flowing water (Pa), τ_c is critical shear (Pa), and “a” is a constant equal to one in the WEPP model (Elliot and Laflen, 1993; Flanagan and Nearing, 1995). No detachment occurs when shear in the rill is less than critical shear value of the soil. Hydraulic shear is calculated by

$$\tau = \gamma RS \quad (2)$$

where γ is the specific weight of water (N m^{-3}), R is the hydraulic radius of the rill (m), and S is the hydraulic gradient which approximately equals the slope of the rill bottom.

Baseline rill erodibility and critical shear stress represent erodibility characteristics of freshly tilled soil. Rill erodibility and critical shear stress are adjusted in the model by multiplying baseline values of these two parameters by adjustment factors. Adjustment factors are calculated in WEPP to account for incorporated residue, temporal changes in roots, sealing and crusting, and freezing and thawing (Flanagan and Nearing, 1995).

Our objective was to evaluate the WEPP model by comparing predicted infiltration, runoff and soil erosion with field measurements from two, one-year furrow irrigation studies. The first study involved four tillage treatments on one field and the second study included three furrow inflow rates on two fields with different crops.

Materials and Methods

Field Measurements – Study 1

The first study was conducted at the Northwest Irrigation and Soils Research Laboratory near Kimberly, ID. It involved four tillage treatments: disk (D), paratill (P), disk and paratill (DP), and no-till (NT). The soil was Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic calciorthid) on a uniform 0.8 % slope (table 1). Barley (*Hordeum vulgare*, L.) was grown the year prior to infiltration, runoff and soil erosion measurements. Following barley harvest in 1995, stubble was cut about 80-mm high, baled and removed from the plots. The D and DP plots were disked after straw was removed in the fall of 1995 and in the spring of 1996 before planting dry beans (*Phaseolus vulgaris* L.). DP and P plots were paratilled approximately one month before planting. Paratill shanks were spaced 1.5 m apart. Each shank tilled the bed between two, 1.1-m spaced irrigation furrows. Thus, irrigation furrows were not disturbed by paratilling. Two dry bean (Viva pink) rows were seeded 0.56-m apart between 1.1-m spaced irrigation furrows. Dates for 1996 field operations and irrigations are listed in table 2.

The field was irrigated six times during the growing season using water from the Twin Falls Canal Company ($\text{EC} = 0.5 \text{ dS m}^{-1}$, $\text{SAR} = 0.4\text{-}0.7$). Irrigation duration varied from 10 to 24 h (table 2). Water was supplied to the furrows by 19-mm diameter siphon tubes from a concrete ditch. Inflow rates were not set identically for all furrows so average inflow rates among tillage treatments varied by 10 to 20%.

All irrigations were monitored for water flow and sediment loss except the third irrigation because a herbicide with 48-h re-entry time was sprayed the day before. During the other five irrigations, four furrows in each plot were monitored approximately 85 m from the irrigation ditch, which was about one-third the length of the field. Two of the furrows were wheel-

compacted when furrows were made. The other two furrows were wheel-compacted during planting and paratilling. Monitoring the upper third of the field resulted in higher erosion rates than at the end of the plots because erosion tends to occur near the upper end and deposition near the lower end of a uniform slope (Brown and Kemper, 1987, Trout, 1996).

Water flow rate in irrigation furrows was measured with small, long-throated trapezoidal flumes. Sediment concentration samples were collected from the flume discharge and poured into 1-L Imhoff cones. Sediment concentrations were read after settling for 30 minutes (Sojka et al., 1992). Initial flow readings and sediment samples were taken approximately 15 min after flume discharge began. Data collection intervals increased from 30 min to 4 h during the irrigation. Data were not collected during the night on 24-h irrigations, but a final flow reading and sediment sample were collected at the end of each irrigation. Inflow rates from each siphon tube were measured periodically during each irrigation with a calibrated bucket and stop watch. Furrow infiltration for each measurement interval was calculated by subtracting runoff volume from inflow volume. Infiltration volume was then converted to infiltration depth by dividing by irrigated area (1.1 m by 85 m).

Soil loss from each furrow was calculated by multiplying runoff volume by sediment concentration. Soil loss from each furrow was divided by furrow spacing (1.1 m) to give soil loss per unit field width (kg m^{-1}), similar to the WEPP model output.

Field Measurements – Study 2

Data for study 2 were taken from Trout (1996). This study was conducted on two fields, both Portneuf silt loam, at the Northwest Irrigation and Soils Research Laboratory near Kimberly, ID. Field measurements for study 2 were similar to study 1 except three inflow rates were used during each irrigation. A medium inflow rate was chosen prior to each irrigation to give a 2-h advance time and 35% runoff. High and low inflow rates were 20% above and below the medium inflow rates, respectively. All irrigations lasted 12 h.

Field 1 was 204-m long with 1.3% slope (table 1). This field was moldboard plowed, roller harrowed and planted to dry beans. It was irrigated six times and all but irrigation 5 were monitored. Field 2 was 256-m long with 0.52% slope (table 1). This field was disked in the fall, roller harrowed in spring and planted to corn (*Zea mays* L.). Only six of the nine irrigations on this field were monitored.

WEPP Model Simulations

Version 95.1 of the WEPP model was run in continuous simulation mode. A one-year simulation run was made for each tillage treatment of study 1. Similarly, a one-year run was made for each field and furrow inflow rate of study 2. The weather generator program of WEPP (CLIGEN) was used to generate a climate file for Kimberly, ID. One overland flow element (OFE) was used to represent the uniform 0.8% slope on the 85 m long field segment for study 1. Because the maximum OFE length is 100 m, at least three OFEs were needed for study 2. Two slope files, one with three OFEs and one with four, were used for each field. One slope file for field 1 had four, 51-m long OFEs while the other file had three, 68-m long OFEs. The first slope file for field 2 had four, 64-m long OFEs and the second file had one, 86-m and two, 85-m long OFEs. Only predicted values from four OFE simulation runs for study 2 are presented in comparisons with field measurements.

The baseline critical shear value of 3.5 Pa in the WEPP Portneuf soil file had to be reduced because hydraulic shear in irrigation furrows on Portneuf soil tends to range from 0.25 to 2.25 Pa (Trout, 1992). Rather than choosing a number at random, two methods were used to calculate baseline critical shear and rill erodibility from hydraulic shear and detachment capacity data from WEPP field research (Elliot et al., 1989). The first method involved a linear regression of detachment capacity and hydraulic shear data using shear values less than 4 Pa. Rill erodibility equals the slope and critical shear equals the y-intercept divided by the slope (equation 1). This method resulted in a baseline critical shear of 2.4 Pa and baseline rill erodibility of 0.0042 s m^{-1} . For the second method, a power function was fit to the all hydraulic shear and detachment capacity data to define a shear-detachment relationship at shear values less than 4 Pa (figure 1). Then critical shear and rill erodibility were calculated from the slope and y-intercept of the hydraulic shear and detachment capacity values calculated from the power function. This calculation provided a baseline critical shear of 0.72 Pa and a baseline rill erodibility 0.0021 s m^{-1} (figure 2).

Management files were created to match field conditions as closely as possible. Pink beans were represented by “high fertilization soybean” from the WEPP database. Maximum canopy height, in-row plant spacing and maximum rooting depth were changed to better represent field conditions for dry beans. Crop row spacing had to be changed to 1.1 m for dry bean and 1.5 m for corn because the WEPP model sets the furrow spacing equal to the row spacing. WEPP tillage implement scenarios were edited to match disking, paratilling, planting and bean cutting field operations. Two field operations were not adequately described by WEPP scenarios and had to be defined. First, a new scenario was created for a corrugator, the furrow-forming tool. Second, the WEPP rotary hoe scenario was changed to 10 percent surface disturbance to resemble limited surface disturbance caused by hand weeding with a hoe.

Four irrigation input files were created using average inflow rates for each tillage treatment on study 1. A separate irrigation input file was used for each inflow rate and field for study 2. The only differences among irrigation input files were the inflow rates. Predicted information is only presented for monitored irrigations

Results and Discussion

Overall the WEPP model was easy to use and flexible enough to represent most field input conditions. One major limitation was WEPP automatically setting the furrow spacing equal to row spacing. It is common practice in many areas to irrigate every other furrow or plant two crop rows between irrigation furrows. If row spacings in WEPP were set equal to field row spacings, predicted inflow would have been twice as much as was actually applied.

Crop yield predictions were one-half to one-fourth of the expected yields. Although WEPP was not intended as a yield prediction model, greatly under predicting yield can result in prediction errors of crop residue and water use, both of which affect soil erosion predictions. Yield prediction may have been affected by setting row spacing equal to furrow spacing because the model used a row spacing twice as wide as occurred in the field.

Study 1

The WEPP model accurately predicted runoff for the different tillage treatments used in study 1 (figure 3). Total annual predicted runoff was within 5% of measured runoff (table 3). Infiltration was also predicted reasonably well, but measured infiltration was more variable than

predicted (figure 4). Total annual predicted infiltration was 7 to 22% greater than measured infiltration, with larger differences occurring on paratilled treatments (table 3). Neither runoff nor infiltration predictions were altered by changing baseline critical shear and rill erodibility. Irrigations 2 and 5 had the greatest measured runoff and infiltration volumes because these irrigations lasted 24 h as compared to 10 or 12 h for other irrigations.

Soil loss was not predicted as well as runoff or infiltration. Predicted soil loss was zero for all irrigations and tillage treatments using baseline critical shear of 2.4 Pa and baseline rill erodibility of 0.0042 s m^{-1} . Predicted soil loss, using baseline values of 0.72 Pa and 0.0021 s m^{-1} , was much greater than measured for all irrigations (figure 5). Consequently, predicted annual soil loss was approximately 10 times greater than measured (table 3). Larger errors occurred for the D and DP treatments, indicating that WEPP over-compensated for disking effects on furrow erosion when baseline critical shear and rill erodibility were adjusted.

Study 2

Using three or four overland flow elements had no effect on prediction field average infiltration (figure 6). This result was reasonable because the only conditions that changed were the length and number of OFEs. Predicted runoff, however, was lower when three OFEs were used instead of four (figure 7). Consequently, using three OFEs resulted in lower predicted soil loss (figure 8). The difference between using three and four OFEs possibly occurs because the predicted erosion distribution was not a smooth line between OFEs. A large amount of deposition, for example, was predicted at the beginning of the second OFE on field 2 when four OFEs were used (figure 9). The erosion distribution was similar for three OFEs, but more deposition occurred at the beginning of the second OFE when four OFEs were used.

Predicted values from only the four OFE simulations are presented in comparisons with field measurements. Runoff was not predicted as well for study 2 as for study 1. This result may be partially attributed to longer field lengths, multiple overland flow elements and lower runoff volumes in study 2. Field measurements for study 2 were also taken at the end of the field compared to the upper third of the field in study 1. For field 1 the WEPP model predicted zero runoff for all irrigations using the low inflow rate and the last three irrigations for the medium inflow rate (figure 10). Similarly for field 2, zero runoff was predicted for the last three irrigations using the low inflow rate (figure 11). Predicted annual runoff was 20 to 100% low for field 1 and 90 to 140% high for field 2 (table 4). Separate linear relationships were observed between measured and predicted runoff for the first three irrigations on field 2 (figure 11). There were no linear relationships for the remaining irrigations on field 2 or for field 1 because predicted runoff was zero using the low inflow rate (figure 10).

Predicted annual infiltration was 50 to 80% higher than measured for field 1 and about 10% lower than measured for field 2 (table 4). Higher predicted infiltration cannot be explained by higher crop water use because predicted yields were low. Predicted infiltration matched measured infiltration fairly well on field 1 (figure 12) and on field 2 with the exception of irrigation 1 (figure 13).

Soil loss predicted by the WEPP model tended to be either too high or zero (figures 14 and 15). Since no runoff was predicted using the low inflow rate on field 1, predicted soil loss was zero. With critical shear of 2.4 Pa and rill erodibility of 0.0042 s m^{-1} , predicted soil loss was greater than zero for only two medium inflow rate irrigations and four high inflow rate irrigations. No soil loss was predicted for any irrigation using these soil parameters on field 2. It is important

to note that measured soil loss was also zero for the first irrigation and last three irrigations on field 2 using low and medium inflow rates. Using the second set of soil parameters ($\tau_c = 0.72$ Pa, $K_r = 0.0021$ s m⁻¹), predicted annual soil loss was 2 to 3 times greater than measured for field 1 and 10 to 60 times greater than measured for field 2 (table 4).

Some of the soil loss prediction errors resulted from runoff and/or infiltration prediction errors. For irrigation 1 on field 2, for example, predicted runoff was much higher than measured (figure 11) and predicted infiltration was much lower than measured (figure 13). Higher predicted runoff resulted in soil loss predictions of 200 to 275 kg m⁻¹ when measured soil loss was less than 5 kg m⁻¹ (figure 15).

The WEPP model might predict soil loss more accurately if a non-linear relationship were used to calculate detachment capacity from critical shear, especially for the low hydraulic shear that occurs in irrigation furrows. Kemper et al. (1985) suggested that critical shear is zero in irrigation furrows because essentially no threshold shear is required to initiate erosion in dry furrows. Critical shear can equal zero when using a power function. The power function in figure 1 has a higher coefficient of determination than the linear function. Higher coefficients of determination also occurred for power functions for 25 of the other 32 cropland soils tested during WEPP field erosion measurements. Power functions increased coefficients of determination by 0.03 to 0.22 with an average increase of 0.12. Portneuf and three other soils picked at random are shown in table 5 as an example.

Another possible improvement to the WEPP model would be to account for irrigation water quality. Lentz et al. (1996) measured significantly higher soil loss when high sodium adsorption ratio (SAR) and low electrical conductivity (EC) irrigation water was used as compared to low SAR or high EC irrigation water. Brown et al. (1988) also noted greater infiltration and soil erosion occurred when clear irrigation water was used as compared to irrigation water containing sediment.

Conclusions

The WEPP model predicted infiltration and runoff reasonably well when one, 85-m long overland flow element was used to represent the upper third of a field. Predicted infiltration and runoff were not as good for longer fields with multiple overland flow elements. Infiltration predictions may be improved if the furrow spacing did not automatically equal the row spacing in WEPP.

Soil loss was not accurately predicted from any field. Some of the soil loss prediction errors were caused by the model inaccurately predicting that no runoff occurred and therefore no soil loss. The linear relationship between detachment capacity and hydraulic shear used by WEPP also resulted in soil loss predictions that were too high or zero. A power function may result in more accurate erosion predictions, especially under low hydraulic shear conditions that occur in irrigation furrows.

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Table 1. Field conditions for studies 1 and 2.

	Crop	Length (m)	Slope (%)	Row Spacing (m)	Furrow Spacing (m)	Previous Crop
Study 1	Dry bean	85	0.8	0.56	1.1	Barley
Study 2, Field 1	Dry bean	204	1.3	0.56	1.1	Potato
Study 2, Field 2	Corn	256	0.5	0.76	1.5	Peas

Table 2. Field operations and activities for study 1.

Date	Operation/Activity
April 25	Disk D and DP treatments
May 2	Paratill DP and P treatments
May 2	Corrugate
May 7-9	Irrigation 1: 12 hours
June 3-4	Plant beans
June 6	Corrugate
July 1-2	Irrigation 2: 24 hours
July 10	Spray
July 11-12	Irrigation 3: 12 hours (did not monitor)
July 19	Hand weed all plots
July 24-25	Irrigation 4: 12 hours
Aug. 6-7	Irrigation 5: 24 hours
Aug. 16	Hand weed all plots
Aug. 20-21	Irrigation 6: 10 hours
Sept. 3-4	Cut beans
Sept. 11-12	Harvest beans

Table 3. Annual measured and predicted runoff, infiltration and soil loss for study 1.

Tillage	Infiltration		Runoff		Soil Loss	
	mm		mm		kg/m	
	measured	predicted	measured	predicted	measured	predicted
D	439	471	960	972	75	859
DP	383	470	931	898	55	785
NT	445	476	964	917	21	220
P	407	475	933	940	32	231

Table 4. Annual measured and predicted runoff, infiltration and soil loss for study 2.

Inflow Rate	Infiltration		Runoff		Soil Loss		
	mm		mm		kg/m		
	measured	predicted	measured	predicted	measured	predicted 1 [*]	predicted 2 [†]
Field 1							
Low	159	241	78	0	69	0	0
Med	163	276	117	39	165	6	301
High	164	301	164	130	286	470	924
Field 2							
Low	322	279	77	149	5	0	298
Med	332	302	133	274	15	0	494
High	336	313	231	554	72	0	840

^{*} Baseline critical shear of 2.4 Pa and baseline rill erodibility of 0.0042 s m⁻¹.

[†] Baseline critical shear of 0.72 Pa and baseline rill erodibility of 0.0021 s m⁻¹.

Table 5. Baseline soil parameters calculated by linear regression and power function.

Soil	Location	Linear Regression [*]			Power Function [†]		
		τ_c	$K_r \times 10^3$	R^2	b	a	R^2
		(Pa)	(s m ⁻¹)				
Portneuf silt loam	Kimberly, ID	2.9	9.1	0.71	0.27	2.5	0.85
Grenada silt loam	Como, MS	5.3	8.5	0.65	0.01	3.4	0.71
Opequon clay loam	Flintstone, MD	5.0	2.8	0.61	0.14	2.0	0.69
Whitney sandy loam	Fresno, CA	4.5	20.4	0.59	0.07	3.2	0.65

^{*} $D_c = K_r(\tau - \tau_c)$

[†] $D_c = b(\tau)^a$

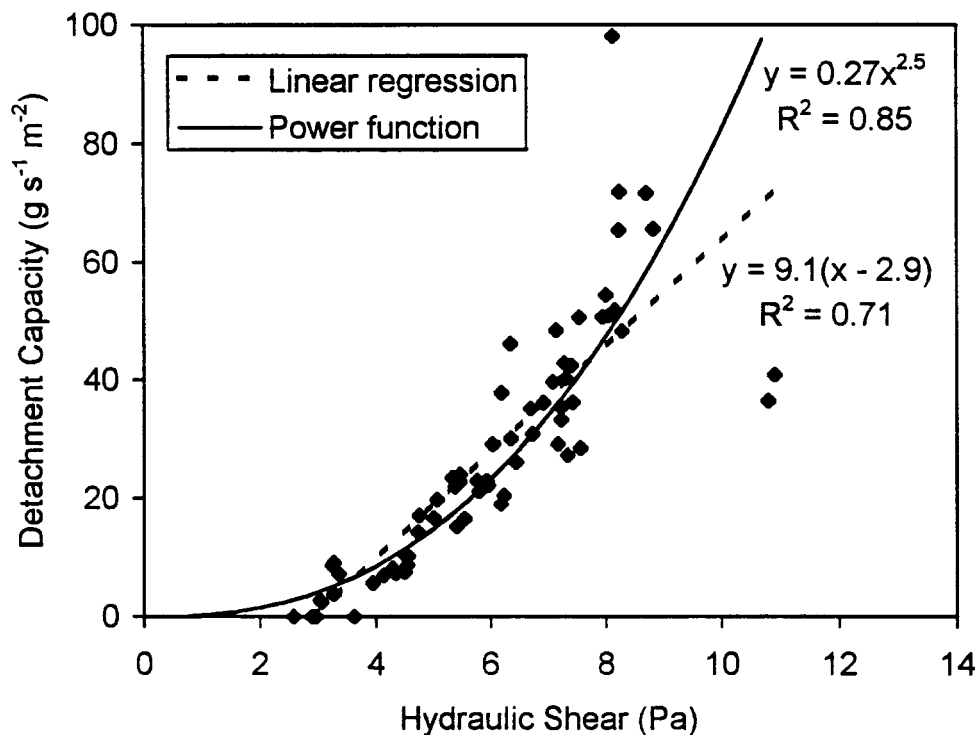


Figure 1. Detachment capacity - hydraulic shear relationship for Portneuf silt loam.

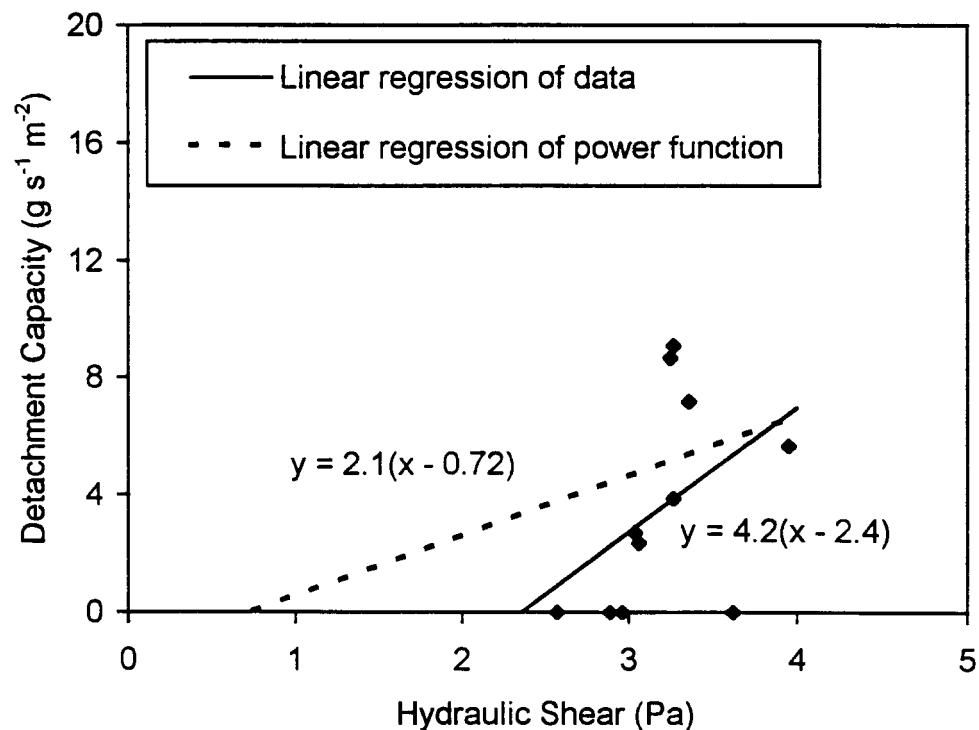


Figure 2. Baseline critical shear - rill erodibility relationships for hydraulic shear < 4 Pa.

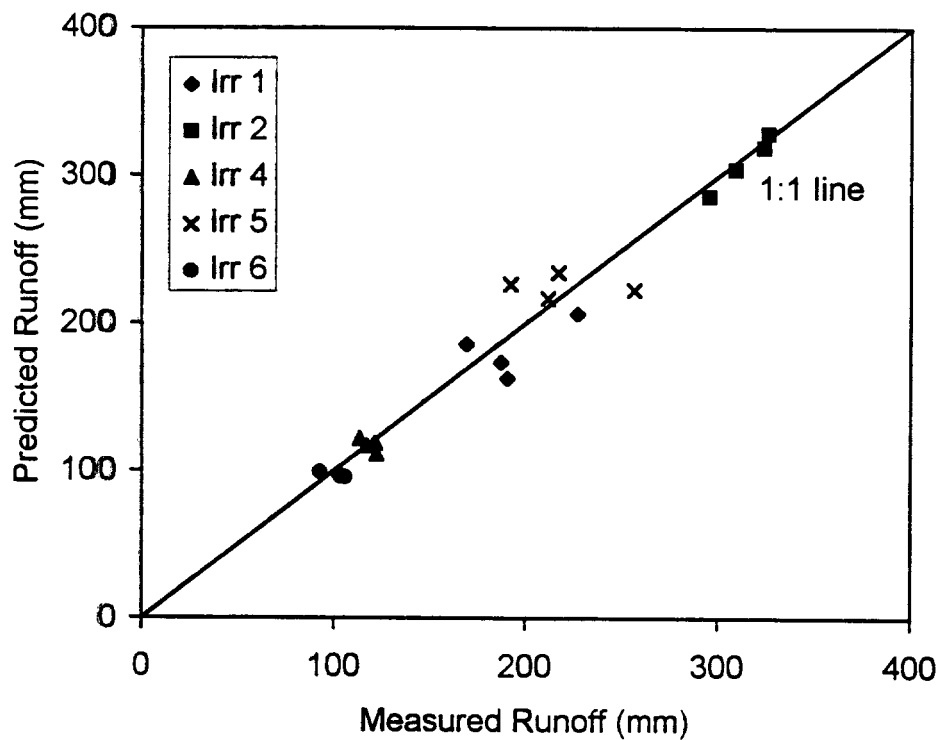


Figure 3. Predicted vs. measured runoff for study 1.

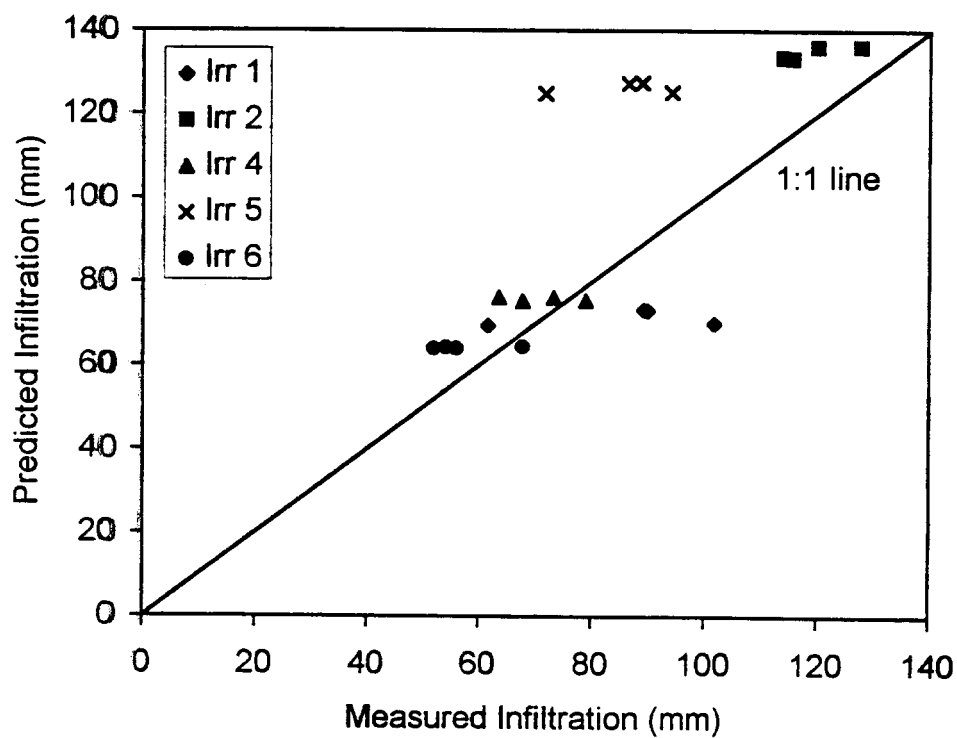


Figure 4. Predicted vs. measured infiltration for study 1.

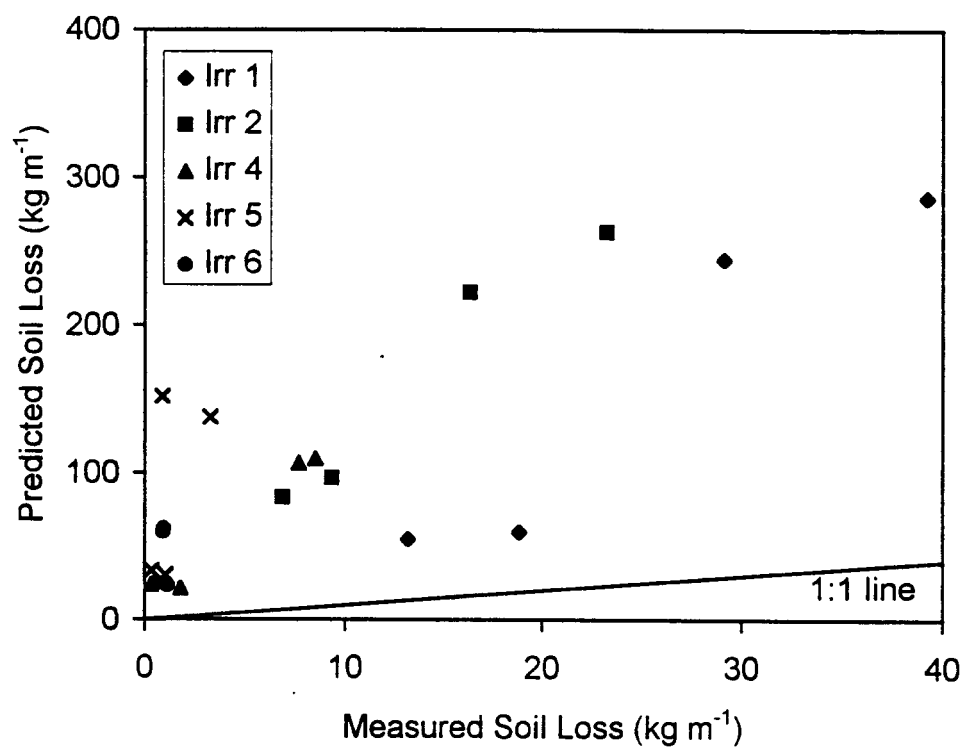


Figure 5. Predicted vs. measured soil loss for study 1.

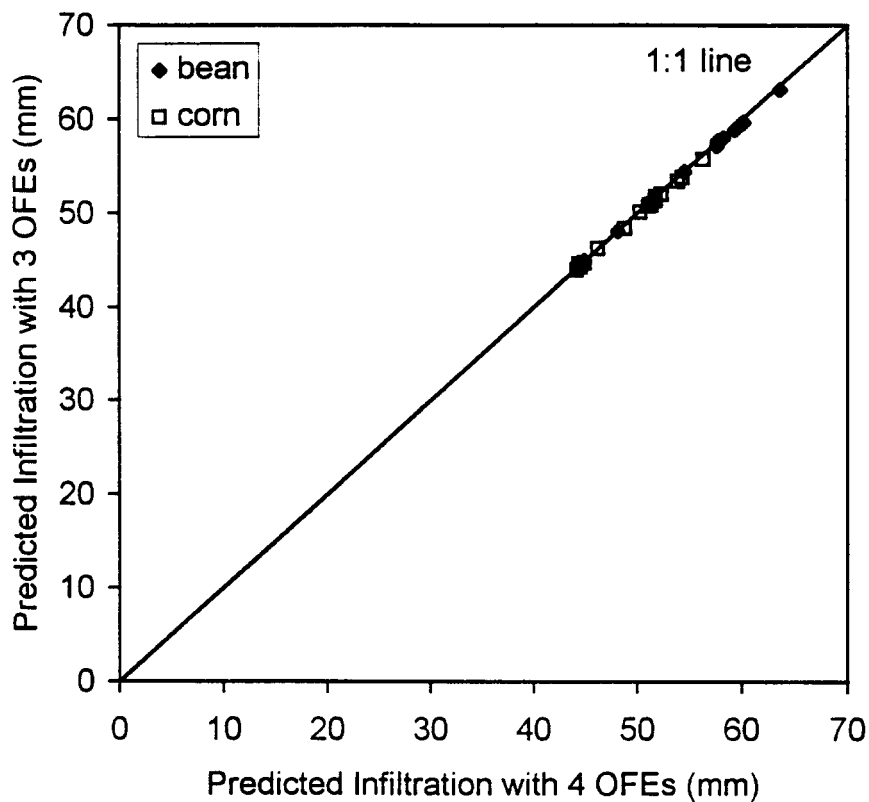


Figure 6. Relationship between infiltration predicted with three and four overland flow elements.

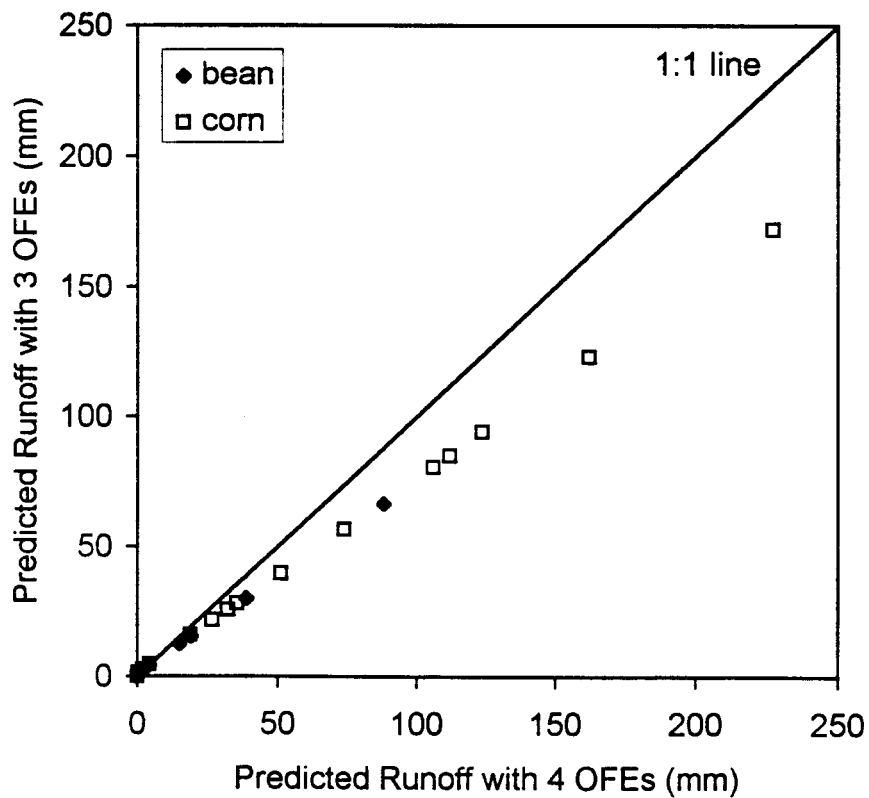


Figure 7. Relationship between runoff predicted with three and four overland flow elements.

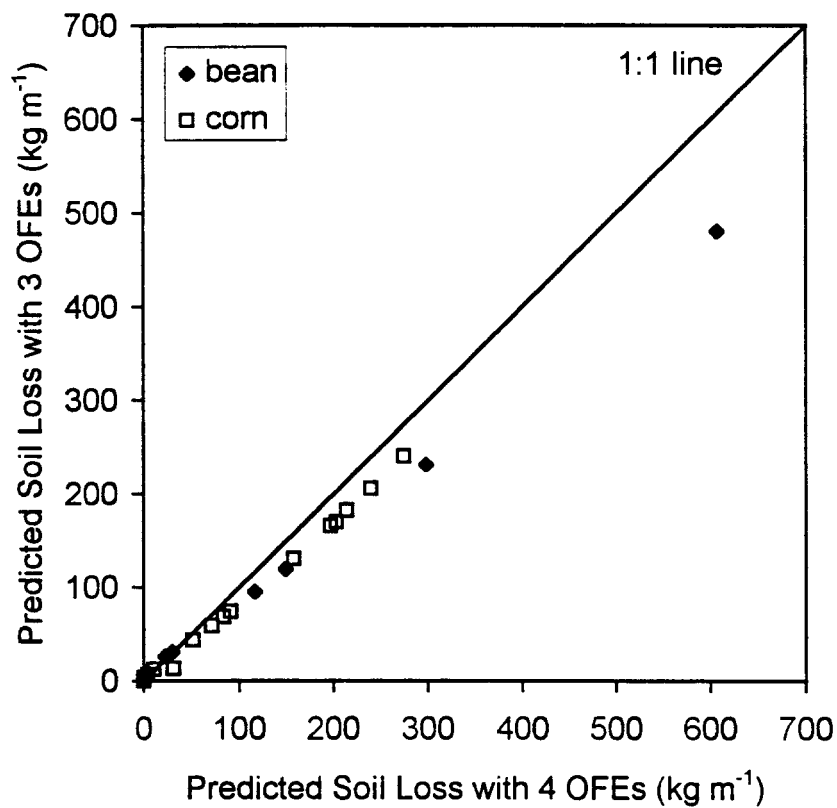


Figure 8. Relationship between soil loss predicted with three and four overland flow elements.

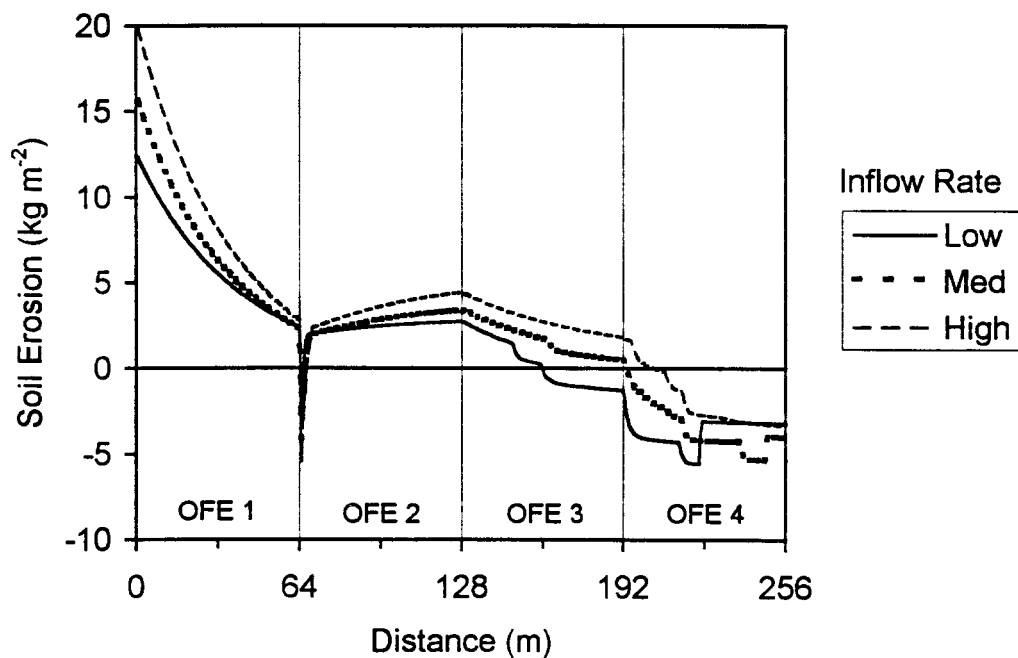


Figure 9. Predicted soil erosion distribution for study 2, field 2 with 4 overland flow elements.

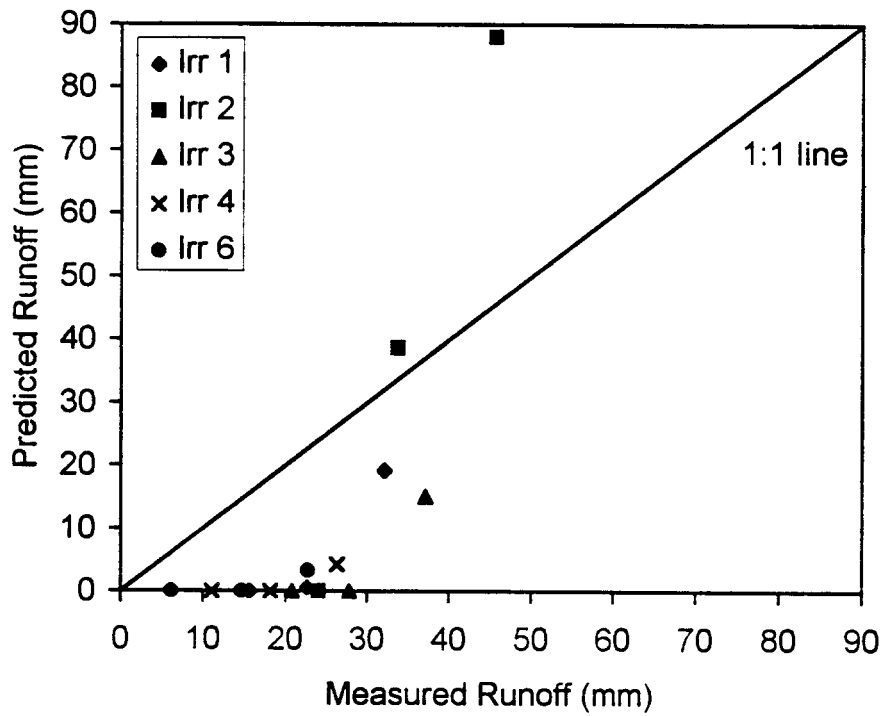


Figure 10. Predicted vs. measured runoff for study 2, field 1.

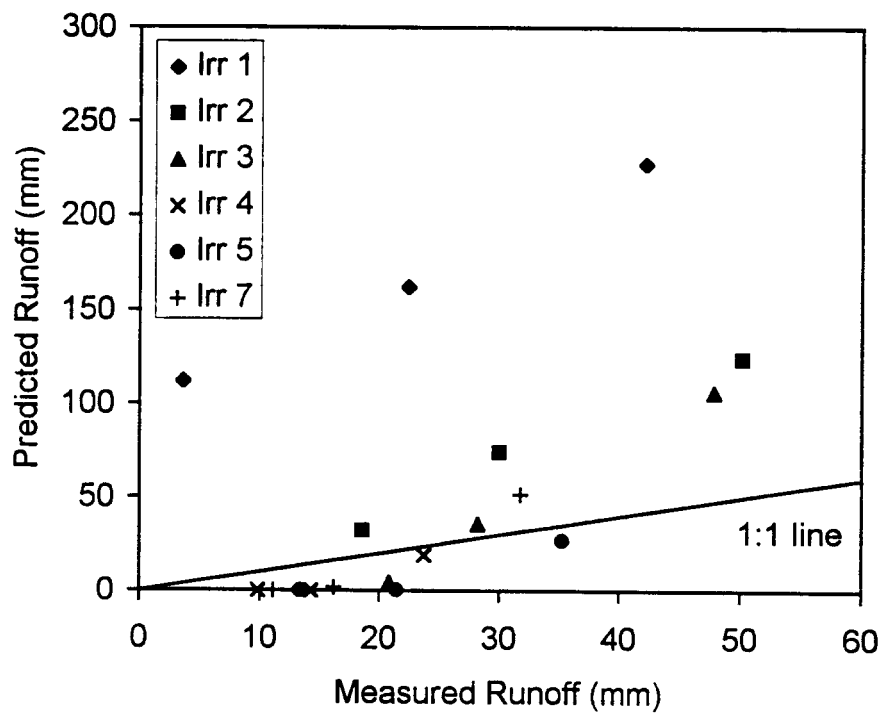


Figure 11. Predicted vs. measured runoff for study 2, field 2.

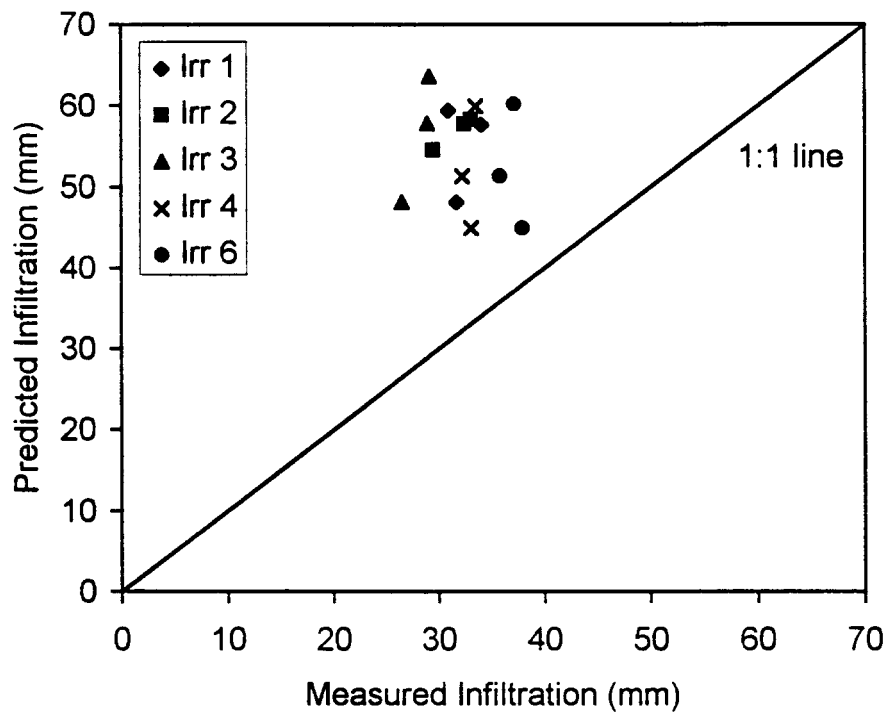


Figure 12. Predicted vs. measured infiltration for study 2, field 1.

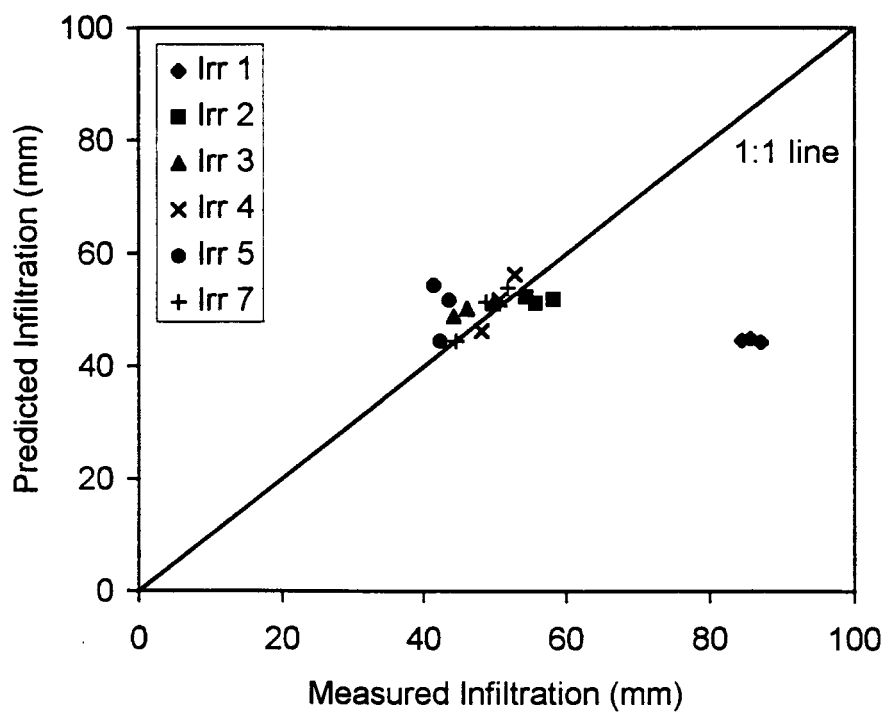


Figure 13. Predicted vs. measured infiltration for study 2, field 2.

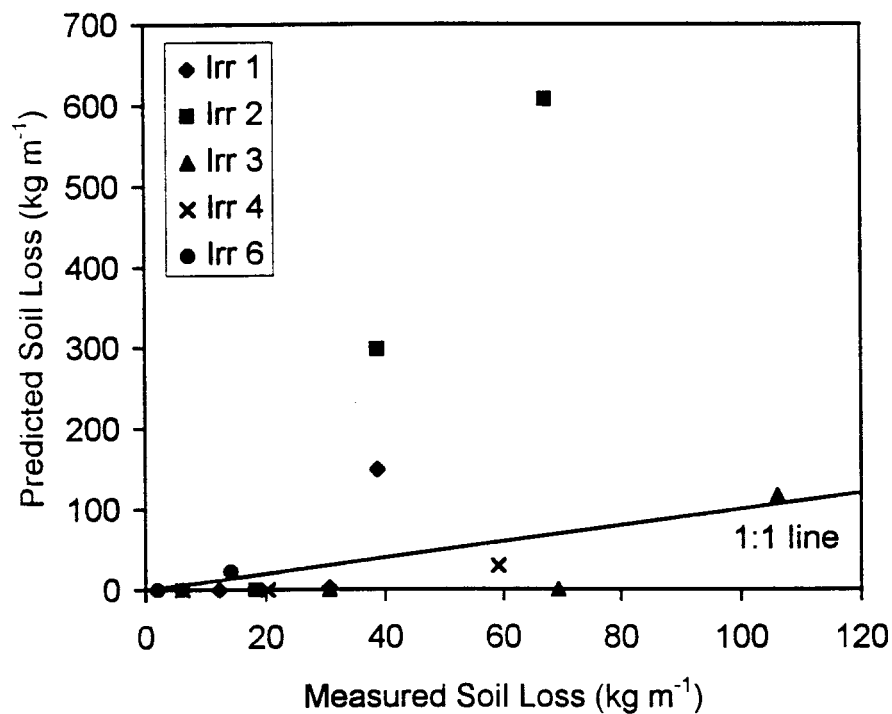


Figure 14. Predicted vs. measured soil loss for study 2, field 1.

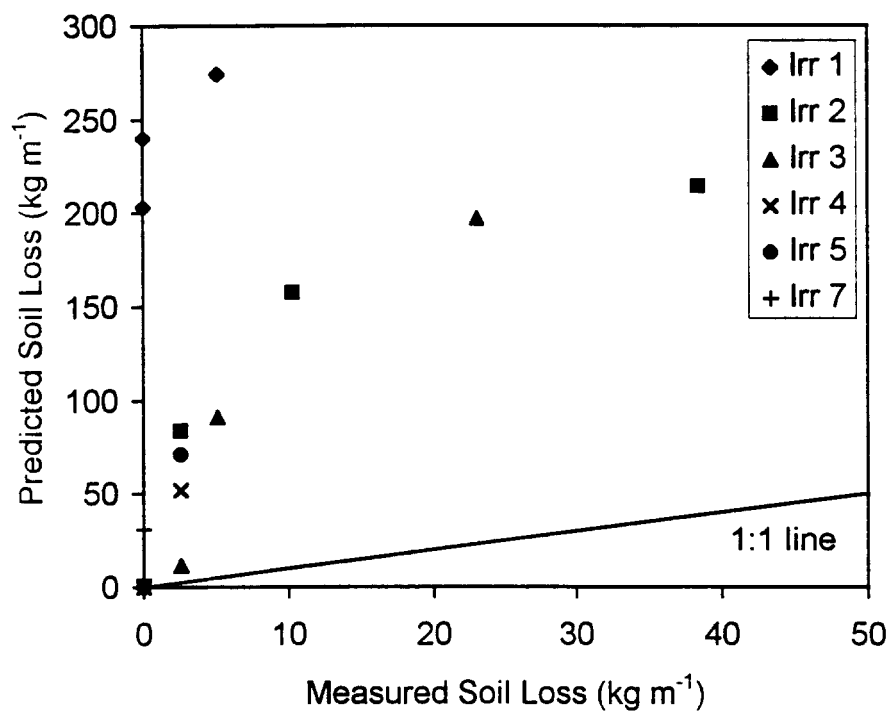


Figure 15. Predicted vs. measured soil loss for study 2, field 2.